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An Inside Look Into Doppler Ultrasound

by

Lora Alison Taylor

**A University Honors Department Senior Project and a
College Scholars Department Senior Project**

University of Tennessee, Knoxville

May 1997

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Contents

I. Abstract	1-2
II. Introduction	3
III. Historical Perspective	4-10
IV. Basic Principles of Doppler Ultrasound	11-15
V. Instrumentation	16-18
VI. Factors Which Can Affect Results	19-20
VII. Echocardiography	21-24
VIII. Case Study	25-30
IX. Future Trends	31-33
X. Conclusion	34
XI. Acknowledgments	35
XII. References	36-37

An Inside Look Into Doppler Ultrasound

Abstract

Over the past decade, with the advancement of technology, there have been dramatic changes in ultrasound instrumentation and application. Some of these technological improvements include better resolution, increased portability, specialized probe design, and the use of more sophisticated computer enhanced processing (Christensen et al., 1994).

Despite these technological improvements, ultrasound has long been recognized to have many advantages over other types of imaging. For example, it is non invasive, non ionizing, readily available, and relatively inexpensive (Christensen et al., 1994). Traditional real-time ultrasound imaging provides functional motion data, as well as information about the internal architectural structure of organs (Toal, 1994). With the advent of spectral and color Doppler capabilities, ultrasonographic imaging has expanded its role in disease assessment.

The technological advancements, widespread education, and the subsequent recognition of its many applications have lead to an increased use of Doppler ultrasound as an adjunct for early detection of heart and vascular conditions, as well as other diseases including cancer. Doppler ultrasound involves the analysis of the changes in the blood flow characteristics within the target vessels, and the resulting

comparison of the data with normal values. This can lead to a more complete and accurate diagnosis than was possible with ultrasound imaging techniques alone.

The purpose of this project is to trace the historical developments which led to the technology of Doppler ultrasound, to demonstrate the modern-day medical application of Doppler ultrasound by analyzing its role in heart disease evaluation in an actual case setting, and finally to hypothesize on its probable future role in medicine.

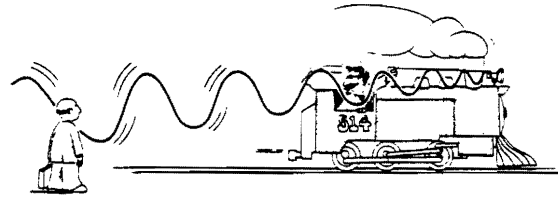
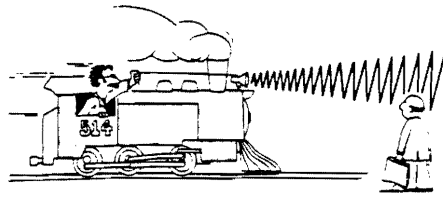
Introduction

In this era of soaring health-care costs and rising concern over cancer and radiation exposure, ultrasound imaging has gained popularity as a non-invasive, non-ionizing, and relatively inexpensive diagnostic tool. Additionally, with the dramatic revolution in the computer and electronics field, technological improvements in instrumentation have led to increased "user-friendliness," better image quality, and greater diagnostic capability. For these reasons, ultrasound has now become an integral component in many clinical settings. As technology continues to evolve, new techniques will be formulated, and ultrasound will gain an even greater role in aiding the physician in detecting disease.

Historical Perspective

The Doppler Effect

The Doppler Effect was first described by the Austrian physicist, Christian Johann Doppler. During the time of his discovery he was a professor of elementary mathematics and practical geometry at the State Technical Academy in Prague, Czechoslovakia. On May 25, 1842, the principle which now bears his name was stated as "Ueber das farbige Licht der Doppelsterne und einigeranderer Gestirne des Himmels." (Webb, 1993, p. 2). The wavelength of light or sound varies according to the relative motion of the source of the light or sound and the observer (Bushong, 1993). Doppler elaborated on his principle with an explanation of how the observed frequency changes relative to the direction of motion (Webb, 1993). For example, if the source, observer, or both are traveling toward each other, the emitted sound waves will reach the observer at a higher frequency. This results in a higher pitch being heard. On the other hand, if the source and observer are moving apart, the observed waves will have a lower frequency and therefore a lower pitch sound will be heard (Bushong, 1993). An everyday illustration of the Doppler Effect occurs when vehicles with sirens or whistles approach and then pass. For instance, as a train approaches the observer the sound of the whistle appears very high pitched (high frequency). After the train has passed the individual, there is an abrupt change to a lower pitch or lower frequency (Bushong, 1993).



Doppler effect describes the apparent change in frequency of emitted sound when either the source or the receiver is in motion. As a train passes, the pitch of its whistle changes from high to low.

(Bushong, 1993, p. 513)

Christian Doppler received verification of his principle in 1845 by Christoph Buys Ballot who was working at Utrecht in Holland. In 1848, Armand Fizeau, a French physicist, performed research on the Doppler effect and its application to light. Fizeau was the first to link the Doppler effect to astronomy, and his work formed the foundation for the primary method to determine the distances of galaxies and other distant bodies (Webb, 1993). Stars moving away from the earth produce light that is observed to be "red-shifted." A red-shift corresponds to light of longer wavelength or lower frequency. Reciprocally, stars moving toward the earth appear more blue which corresponds to a shorter wavelength and higher frequency (Bushong, 1993).

Ultrasound

Approximately forty years after the discovery of the Doppler effect, the first basic components necessary for the generation and detection of ultrasound signals were uncovered. The discovery of the piezoelectric effect, and the subsequent investigation into the crystals which contained this property, were ascertained by Pierre and

Jacques Curie in 1880. The first practical application of ultrasound was discerned in 1916 by Langevin. He incorporated the pulse-echo technique into submarine detection. His work formed the basis for SONOR, which was utilized during World War II. SONOR, a pulse-echo, distance ranging technique was the foundation for modern diagnostic medical sonography (Wicks, 1983).

In the late 1930's and early 1940's, high frequency sound, or ultrasound was first applied to peacetime industrial problems. During this time Sokolov and Firestone utilized ultrasound devices to detect metal flaws. Using this type of industrial equipment, medical researchers began to look for possible medical applications.

One such researcher, Dussik, was the first to apply ultrasound to medical imaging. In 1942 he used a metal flaw detector, which he had refined by amplifying the transmitted signal, to analyze cerebral ventricles. Following Dussik's lead, in 1949 Ludwig and Struthers used the pulse-echo method to detect gallstones and foreign bodies in soft tissue. By the early 1950's, physicians and engineers united in order to develop ultrasound equipment expressly for medical applications. At the same time, a synthetic piezoelectric crystal was developed which allowed for the formation of a compound scanner and also for the improvement of the overall quality of the image (Wicks, 1983). The early ultrasound systems of the 1950's consisted of a "water-filled tank in which the patient was immersed,

surrounded by a track along which the transducer was moved in a series of compound motions. Using the signal amplification and display techniques developed for RADAR, the echoes were displayed on a phosphor screen and photographed" (Wicks, 1983, P. 2). These early ultrasound "images" resembled black and white line drawings and were named bistable images.



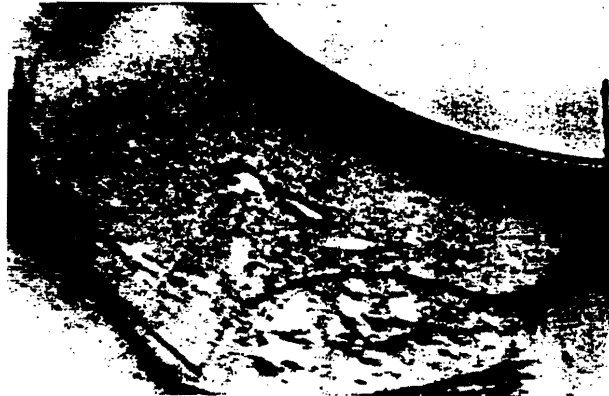
(Bushong, 1993, p. 511)

At this point ultrasound had a notable disadvantage in that the patients must be immersed in water (Wicks, 1983).

By the middle 1950's, diagnostic ultrasound attained wider clinical applications. It was being used as an ophthalmic scanner, to analyze moving cardiac structures, and to image midline structures of the brain. In addition to wider clinical applications, the technology of ultrasound instruments was also continuing to advance. In the late 1950's Donald developed a direct-contact, manually operated scanner. His model provided the concept for the first commercially produced ultrasound scanners in the United States and Britain (Wicks, 1983).

Japan also joined the ultrasound revolution and along with the United States, developed further medical applications for gynecological and obstetric diagnosis (Wicks, 1983). Diagnostic ultrasound was first utilized in obstetric practice in 1966, and is now an integral imaging tool for obstetricians (Bushong, 1993).

Rapid advancements in the field of electronic technology since the late 1950's has had a profound effect on ultrasound instrumentation and image quality. Once the electronic signal was developed, it was quantified and then displayed in varying shades of gray. The shades of gray were known as the gray scale. The range of gray shades corresponded to predetermined intensity levels of returning echoes. By using this gray scale, physicians were able to gain a clearer understanding of the textural information of the organ (Wicks, 1983).



(Bushong, 1993, P. 511)

Further advancements occurred with the incorporation of the computer into ultrasound imaging. Digital signal processing now allows computers to manipulate the ultrasound information. Displays which allow for the rapid detection

and subsequent replacement of the sonographic image have led to the development of real-time scanners (Wicks, 1983). These types of scanners afford an additional advantage to ultrasound by making it possible to obtain dynamic information concerning the target organ. Other innovations include more precise focusing and steering of the ultrasound beam. Each of these technological betterments has led to ultrasound imaging with increased resolution and greater diagnostic capabilities.

Current ultrasound imaging has only a few disadvantages or limitations. The major disadvantage is its inability to obtain images from structures obscured by bone, air, or bowel gas (McGahan, 1990). Other limitations include the amount of training required to operate the unit, select the appropriate settings, and to recognize artifacts and their meanings. Finally, knowledge of the three-dimensional anatomy of soft tissue structures is necessary (Christensen et al., 1994).

Doppler Ultrasound

The utilization of the Doppler Effect in conjunction with standard ultrasound imaging techniques is a relatively recent phenomenon. The basic physical principles that make Doppler blood flow measurement possible have been understood since World War II, but it has been only in the past ten years that these principles have been successfully incorporated into diagnostic imaging. Over the past decade, "successive generations of equipment have evolved rapidly,

from crude, continuous-wave Doppler flow detectors that originally provided the user with a poorly localized audible Doppler signal for aural analysis of blood cell velocities to the current state of the art color flow mapping systems and duplex systems that combine real-time ultrasound imaging with pulsed Doppler techniques" (Taylor & Holland, 1990, P. 297). These duplex scanners provide real-time images along with the Doppler detection of motion (Bushong, 1993).

A new addition to Doppler Ultrasound has been the incorporation of digital color Doppler. With this type of color imaging, even the direction of blood flow is shown. An acronym for the blood-flow direction is BART or Blue Away, Red Toward. The relative velocities of the flow can also be ascertained by monitoring the intensity of the color (Bushong, 1993).

Doppler Ultrasound shows in both picture and sound the flow and turbulence of red blood cells. Subtle changes in blood flow characteristics can be determined by analyzing the differences in the original versus the returned sound waves. Sonologists can use this information to determine how much irregularity exists or whether blood is flowing at all (Sochurek, 1988).

"The evolution of Doppler Ultrasound was accelerated by a growing appreciation of the tremendous potential and by advances in electronics which have made available the high speed digital integrated circuits required to achieve the performance offered by modern systems. The introduction of

electronically steered, phased array transducer systems and the application of sophisticated signal processing and display techniques for analyzing received ultrasound echoes have been the two most important technological improvements recently made in Doppler instrumentation" (Taylor & Holland, 1990, p. 298).

Basic Principles of Doppler Ultrasound

Doppler Effect and Equation

The Doppler Effect is defined as the change in frequency or wavelength of a wave due to the motion of the wave source, receiver, or reflector of the wave. This effect is calculated mathematically with the Doppler equation (Kremkau, 1990).

$$f_D = \frac{2f v(\cos\theta)}{c}$$

C = velocity of sound in soft tissue, 1540 m/s

f_D = frequency shift measured by the machine

f = selected frequency setting of the machine

θ = angle of the incoming pulse

v = speed of source, receiver, or reflector

The Doppler equation indicates that the Doppler shift is proportional to the ratio of the speed of the moving object to the wave propagation speed. The medical application of this phenomenon is that the measured shifts are proportional to blood flow speed. Since stationary transducers are used to emit and receive the sound, the

Doppler shift observed is the result of the motion of the red blood cells (Kremkau, 1990).

In addition to measuring red blood cell velocity, the Doppler shift can also indicate the direction of the flow by producing either a positive or negative frequency shift. If the red blood cells are moving towards the transducer, the frequency of the returning signal is increased, which subsequently produces a positive Doppler shift. On the other hand, if the red blood cells are moving away from the transducer, the frequency of the returning signal is decreased, producing a negative Doppler shift (Evans et al., 1989).

Spectral Doppler

When first developed, Doppler units would take the returning wave frequency and convert it to an audible sound with the highest audible signal correlating to the portion of the vessel where maximum flow was occurring. Variance in the audible signal was used to differentiate between arterial and venous flow because veins typically have a low-pitched hum, but arteries tend to have a more variable pattern with a high-pitched systolic component (Evans et al., 1989).

As Doppler technology improved, the audible signal was supplemented with a display of the amplitude by the frequency components. This task is performed by a spectrum analyzer, which breaks down a time-varying waveform into the individual frequencies, analogous to a prism separating

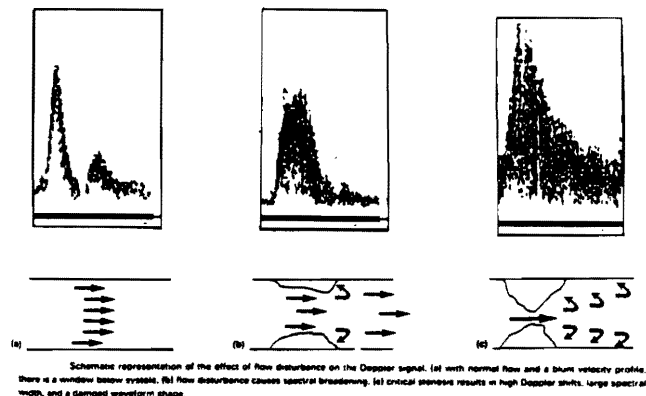
white light. The process is done with a real-time fast Fourier transform analyzer. The output is displayed as a graph on a scrolling screen (Taylor & Holland, 1990). The vertical axis corresponds to the frequency shift. The brightness of the gray scale is a measure of amplitude or power, which is proportional to red blood cell density. Finally, time is represented on the horizontal axis (Burns, 1987).

Spectral analysis is a useful method to quantitate flow velocity. Through the Doppler equation, blood flow velocity can be determined using the Doppler shift frequency information. Current ultrasound units with Doppler capabilities display velocity information directly on the screen, with the peak velocity of the red cells plotted over time (Taylor & Holland, 1990). Variations in red blood cell velocities per unit of time produce corresponding changes in the appearance of the spectrum. There are a number of conditions that might effect the flow characteristics of red blood cells within a vessel.

Standard spectral profiles have been discerned based on the type of flow which is present in a given vessel. Four basic flow types/spectral profiles exist normally. Plug flow is evident in large blood vessels, especially during systole. It is characterized by having a constant fluid speed across the entire width of the vessel. This type of flow produces a very "clean" spectral profile. Laminar, or parabolic flow is found in smaller vessels in diastole.

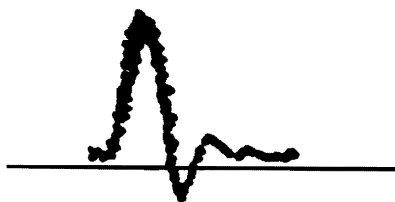
With parabolic flow there is maximum flow in the center of the vessel and minimum flow along the vessel edges. Since the red blood cells are not all moving at the same speed, some spectral broadening is evident in the spectral profile. Spectral broadening is defined as a "vertical thickening of the spectral trace" (Kremkau, 1990, P.42).

This effect is even more evident in the profiles resulting from disturbed or turbulent flow. Disturbed flow is often found at bifurcations within the vessel. Turbulent flow is not normally found in the body unless beyond an obstruction. As flow is disturbed or becomes turbulent, greater variations of various portions of the flowing blood produce a greater range in Doppler shift frequency, which corresponds to increasing spectral broadening. An illustration of this effect occurs with a stenosis, or narrowing of the blood vessel. As the blood reaches the narrow portion of the vessel, flow speed is increased. This increase in flow speed at the level of the obstruction can lead to turbulent flow beyond the obstruction. This can be detected by Doppler using spectral broadening. Such information can also be used to indicate the site and degree of the stenosis (Kremkau, 1990).



(Burns, 1987, p. 583)

Spectral analysis can also be used to indicate downstream resistance in arteries. Varying degrees of downstream resistance change the shape of the spectral curve. Large differences between systolic and diastolic peaks in the same trace are indicative of high downstream resistance to flow. If resistance is significantly high, a reversal of flow may be evident, with a small component peak below the baseline, at or during diastole. In some cases, this flow reversal may be followed by a second peak above the baseline as a result of the elastic recoil of the vessel wall driving red cells forward again. This event is known as the Windkessel Effect. In contrast to high resistance beds, a small difference between the systolic and diastolic peak of the spectral trace characterizes low downstream resistance with significant flow during diastole.



High resistance flow:
Little or no flow in diastole
Negative deflection in waveform



Low resistance flow:
High diastolic flow
No negative deflection

(Toshiba Radiology Conference)

Knowledge of the standard shapes of spectral curves for various vessels is important in evaluating abnormalities

within the system. For example, if a stenosis is present downstream, there may be a substitution of a high-resistance pattern for a normally low-resistance pattern (Evans et al., 1989).

Instrumentation

Pulsed Doppler

Pulsed Doppler utilizes short bursts of ultrasound which are transmitted at regular intervals (Burns, 1987). Only one transducer is used, which alternates between sending and receiving signals. The amount of time it takes the signal to reach and then return from a particular depth can be used to determine the depth of the structure from which the pulsations are being measured. This is termed range gating.

Pulsed Doppler can therefore be used to detect blood flow within one vessel at a particular depth even if it is surrounded by other vessels. In addition to depth gating, varying gate width also allows the operator to select for a certain sample volume size. Since pulsed Doppler is used in conjunction with the real-time image, location the specific vessel and placing the gate is simplified.

This type of Doppler is useful in detecting occlusions, because a clot can be echo-free, but the Doppler will show no flow. With proper gate placement, pulsed Doppler can detect an occluded vessel even if the flow in the surrounding vessels is normal (Evans et al., 1989).

The only disadvantage of pulsed Doppler is that there is an upper limit to the Doppler shift which can be detected. This limit is equal to half the pulse repetition frequency and is known as the Nyquist limit (Kremkau, 1990). For this reason, pulsed Doppler is not routinely used in cardiac evaluation.

Continuous Wave Doppler

Continuous wave Doppler utilizes a dual-element transducer, with one element sending signals and the other receiving signals continuously. Since the beam is continuous, there is no way to range gate the pulse. Therefore, this type of Doppler is best used when there is only one blood vessel within the axis of the sound beam. For example, in obstetrics it is used to monitor umbilical vessel flow since this vessel lies in the amniotic fluid with no other vessels in close proximity to complicate the signal. Although continuous wave Doppler has a drawback of not providing depth information, it does have the capabilities to accurately measure very high velocities (Kremkau, 1990). Therefore, continuous wave Doppler is ideal for evaluating the heart and great vessels because of their higher blood velocities versus peripheral vessels.

Duplex Scanners

The most common type of duplex scanner incorporates real-time sector imaging with M-mode or Doppler. For Doppler applications, the real-time image is used to select the desired Doppler location. Next, the scanner is switched

to Doppler mode. It is not possible to switch between imaging and Doppler modes very quickly, therefore the image is usually "frozen" on the screen while the Doppler signal is obtained (Burns, 1987).

"Duplex instruments that combine imaging with Doppler allow more intelligent use of Doppler in that they provide information regarding the location of the source of the Doppler signal" (Kremkau, 1992, P. 9). With the use of small gates, even the location within the vessel can be known. These systems have an advantage in that they display anatomic as well as motion and flow information.

Color Flow Doppler

With color flow Doppler, flow direction information is normally superimposed on the two-dimensional gray-scale anatomic scan (Kremkau, 1990). In order to produce such an image, the red cell velocity over a large area is measured by numerous pulsed Doppler signals. Direction and velocity information is quantitated.

With color flow Doppler imaging, the direction of the blood flow is shown by assigning a color map. Blue corresponds to blood flow away from the transducer, while red indicates flow toward the transducer. Velocity information is allocated a different hue of the major color map. In this way a color-coded real-time image of blood flow is produced (Evans et al., 1989). Although color is primarily used to determine the direction of flow, it can also be used to indicate flow disturbance or turbulence.

Along with the spectral broadening, green or white color flashes within the selected vessel can illustrate turbulent flow.

Factors Which Can Affect Results

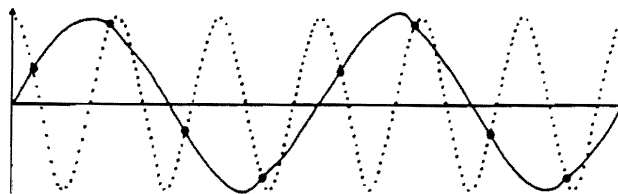
There are several factors which may influence the accuracy of the Doppler results. First, the correct Doppler angle measurement must be selected. Maximum Doppler shift is obtained when the sound is directly opposite the direction of flow. This can be achieved in Doppler echocardiography, in which the Doppler angles are approximately zero (Kremkau, 1990). For peripheral vessels, the transducer beam must be positioned at an angle to the direction of flow. Although this can be corrected using the Doppler equation, in reality there are limitations. A measurement angle of between 30 degrees and 60 degrees is desired. At angles outside this range the results will be compromised. Angles less than 30 degrees result in some sound reflecting at the blood vessel boundary. Angles greater than 60 degrees result in errors of angle estimation and they induce mathematical error to the velocity calculation.

Choosing the correct frequency can also influence the results. Two different events must be balanced with the appropriate frequency selection. Attenuation of ultrasound in tissues occurs more readily with high frequencies. Therefore lower frequencies are necessary for deep tissue analysis. Scattering of the ultrasound in blood is also a

problem. Since one ultrasound wave will encounter approximately 10^5 red blood cells, this causes weakly scattered waves of random phase and amplitude to be reflected. Therefore the use of high frequency is needed to increase the amplitude of echoes received from blood (Taylor & Holland, 1990). In order to balance these two effects, a formula has been generated to calculate the frequency which will achieve the optimum results.

$$\frac{90}{\text{depth in mm}} = \text{operating freq. in Megahertz}$$

With the use of pulsed Doppler, the frequency of the signal cannot be greater than half the sampling rate. When the change in frequency exceeds the sampling view and pulse repetition frequency, the frequency display wraps around so that the signal is seen at both the top and bottom of the image. This technical artifact is known as aliasing, and it can be avoided with correct frequency selection (Evans et al., 1989).



Aliasing. The smaller dots illustrate adequate sampling of an analog signal. The larger dots represent sampling at too low a rate to allow unambiguous reproduction of the analog signal. As these dots are joined together, a signal of the incorrect, or aliased, frequency is produced.

(Burns, 1987, p. 573)

Finally, an appropriate sampling method for the Doppler gate must be chosen. In utilizing the maximum velocity

method, a narrow gate is placed in the center of the vessel to determine the velocity of the center red blood cells. A second technique, the uniform isonation method, places a large gate in the vessel equal to the width of the entire vessel. This measures the velocity of all the red blood cells moving in the vessel. Of the two, the latter is most often chosen.

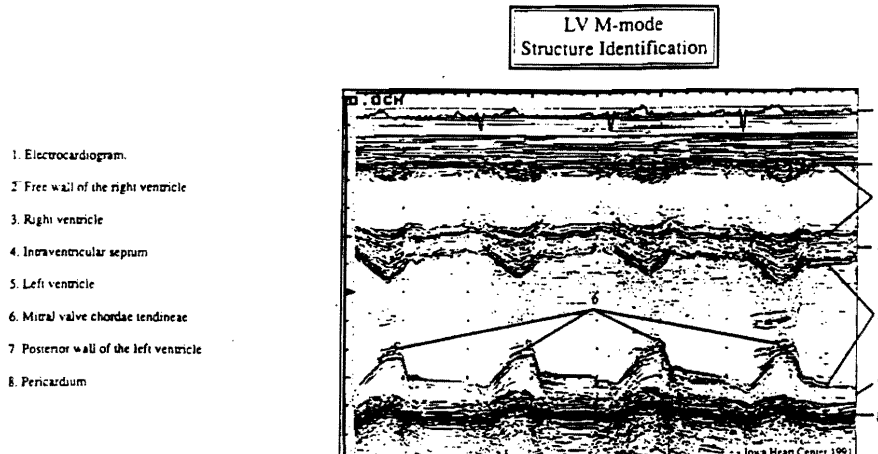
Echocardiography

History and Technological Development

In the early 1950's Doctors Edler and Hertz of Sweden took the basic principles of ultrasound and applied them to the study of the motion of the heart. The technique was introduced in the United States by Wild and Reid in 1957. In 1963 a landmark paper was published by Reid and Joyner at the University of Pennsylvania, which reported on the use of ultrasound in determining the severity of mitral stenosis (Miskovits, 1977).

The early 1970's marked the beginnings of the incorporation of Doppler with echocardiography. "In 1972, Johnson and associates published the first American clinical paper regarding the use of Doppler for detecting flow disturbances by audio characteristics" (Goldberg et al, 1985, p.2). In 1975 the first commercial pulsed Doppler combined with an M-mode locator was released. Motion, or M-mode, provides information along a single path of ultrasound beam. One crystal fires on a line of sight, and then reflects off the various interfaces of the cardiac

structure. The returning echoes are depicted as dots. The series of dots generated by the moving object, the heart, is recorded on a strip of paper moving at a steady speed.



(Toshiba Radiology Conference)

M-mode has the disadvantage that it employs only a unidimensional ultrasound beam. Therefore it is only able to analyze a small segment of the heart at one time (Jawad, 1990).

In an improvement over M-mode, at the University of Washington, Baker and associates produced an instrument which would allow for both two-dimensional imaging and the recording of velocities. Imaging utilizes B, or brightness mode, in which each imaged object is displayed as a dot on the monitor. The intensity of the signal corresponds to the brightness of the gray-scale of the dot. "The advent of two-dimensional echocardiography was a major step forward in cardiac ultrasound in as much as the whole heart could be examined in real time and in two dimensions rather than only one" (Jawad, 1990, p. 58).

Further advancement occurred when Gessert applied the fast Fourier transform to spectral displays, which allowed for the analysis of velocity curve profiles (Goldberg et al., 1985). The most recent betterment in echocardiography technology has been the addition of Doppler color flow imaging. This instrument is capable of demonstrating real-time imaging of flow. First, a two-dimensional B-mode image is recorded. Then, flow data is obtained using range-gated pulsed Doppler. The flow data is displayed in its corresponding color (depending on direction of flow) superimposed on the two-dimensional image and viewed in real time (Jawad, 1990).

The so-called Triplex systems take advantage of the new Doppler color flow imaging by combining it with spectral profile data. The triplex system has three components. First, a two-dimensional B-mode image is recorded. Next, the color Doppler map is superimposed. Finally, a single continuous wave crystal sends one beam through the selected area producing a spectral analysis.

Such recent technological developments and the subsequent clinical applications have enhanced the physician's capability in detecting and diagnosing both congenital and acquired heart disease. "This new technique allows a comprehensive study of the direction, velocity, uniformity and timing of intracardiac blood flow, while simultaneously revealing cardiac structures and their movements" (Missri, 1990, p. 4). Since abnormal flow

patterns can now be visualized, spectral Doppler information can be more accurately incorporated into patient-related decisions (Missri, 1990).

Case Study

Signalment

Breed: Black Miniature Schnauzer

Age: Born 1989

Sex: Male

History

The animal presented to the University of Tennessee Veterinary Teaching Hospital on August 2, 1989 with a history of a heart murmur over the pulmonic valve region.

Diagnosis

Upon examination, a systolic murmur was auscultated loudest on the left base, but it was audible on the right as well. A thorax radiograph was made. The radiograph interpretation included the following: 1) greatly enlarged heart, 2) small peripheral pulmonary vessels, and 3) main pulmonary artery enlargement. An initial radiographic diagnosis of pulmonic stenosis or tetralogy of flow was made.

The following day a nuclear medicine heart shunt analysis was performed in order to evaluate for a right to left cardiac shunt. The results indicated that all activity was localized within the lung and that there was no evidence of an intracardiac shunt. Since an intracardiac shunt is indicative of tetralogy of flow but not of pulmonic stenosis, the nuclear medicine analysis served to rule out tetralogy of flow as a possible diagnosis.

A diagnosis of a pulmonic stenosis was made based on the clinical, radiographic and nuclear medicine results.

Treatment Plan

On November 9, 1989 the dog was re-admitted to U.T. Veterinary Teaching Hospital for further evaluation of the severe pulmonic stenosis. Since the animal had an adverse anesthetic reaction on an initial visit, a nonselective angiocardigram under sedation only was ordered. The results indicated the following: 1) thickening of the right ventricular outflow tract, 2) severely enlarged pulmonary artery (5-6x the diameter of the normal vessel) with abrupt tapering into a normal sized vessel, 3) an apparent bubbled shaped dilation and main pulmonary artery ("cap" formation), and 4) faintly visible distorted valves suggesting the valve may be the site of obstruction with secondary outflow tract thickening contributing to the problem. Propranolol, a beta blocker, was prescribed in order to slow down his heart rate to allow the reduced right ventricular chamber to completely fill with blood.

On November 30, 1989 a right side angiocardigram was performed which showed 1) thickening of the pulmonic valve plane, 2) a stenosis measured to be 5.6 mm, 3) right ventricular hypertrophy, 4) significant stenosis of the right ventricular outflow tract during systole, and 5) a poststenotic dilation of the pulmonary artery.

On the same day, cardiac catheterization was used to evaluate the pressure gradient between the pulmonary artery

and the right ventricle. Normal gradient readings are approximately zero. Readings above this range indicate increasing pressure differences between the two areas as a result of the stenosis hindering blood flow. An initial gradient measurement of 94 mmHg was obtained.

A balloon angioplasty was identified as the desired course of treatment. This procedure was performed on November 30, 1989. Following the first dilation, a gradient of 68 mmHg was measured. Since this value was still in the high range, a second dilation was performed. At this point the pressure gradient reading had been reduced to 56 mmHg.

Treatment Follow-up

The dog was brought in on March 22, 1990 and a thorax radiograph was ordered. Findings indicated persistence in the right ventricular enlargement and prominence of the pulmonary artery segment indicating minimal changes versus previous evaluations. He was brought in for subsequent re-checks on August 17, 1990, May 16, 1991, and May 8, 1992. Tests performed during this time frame include radiographs, echocardiograms, and Doppler. On August 17, 1990 a right ventricular (RV) wall thickness measurement of 9 mm was made. On May 16, 1991, radiographs indicated that the RV wall measurement was unchanged, and Doppler measurements produced a pressure gradient reading of 53.3 mmHg.

Doppler is an excellent way to obtain pressure gradient measurements without necessitating repeated cardiac catheterization on follow-up visits. Reduction in

catheterization is particularly useful in this case because of the animal's history of an adverse reaction to anesthetics. Doppler is used to obtain a value for the peak velocity. In order to arrive at a gradient measurement, the peak velocity values of the right ventricular outflow tract and the pulmonary artery are inserted into the clinically applicable form of Bernoulli's equation.

$$P = 4V_2^2$$

P = Pressure Gradient

V_2 = Velocity downstream of the stenosis

(Missri, 1990, p. 26)

In this way, non-invasive pressure measurements are made using Doppler

On May 8, 1992 a radiograph indicated an increase in the RV wall to 10.1 mm. Doppler was again utilized to obtain a pressure gradient measurement, which was noted as 20.4 mmHg. This was felt to be a spurious value since getting the correct Doppler angle was difficult. However, even though the gradient value was suspected to be inaccurate, Doppler was able to indicate that turbulence was still present beyond the pulmonic valve, indicating abnormal flow.

Upon bringing the animal in for a re-check on September 14, 1993, it was found that the valvular stenosis had begun to scar in, and that another stenosis had begun to form below the original stenosis. The pressure gradient was measured with a cardiac catheter and found to be up to 89

mmHg. At this point, reparative surgery to correct the stenosis was recommended.

On September 15, 1993, a Patch Graft surgery was performed in order to correct the stenotic condition. With this technique, a Gortex arterial graft was sutured over the stenotic area. An incision was made through the pulmonary artery, the stenosis, and the right ventricular outflow tract. This allowed for blood flow from the right ventricle, through the patch graft, and then into the pulmonary artery, in effect bypassing the stenosis.

During a post-operative check on January 14, 1994, the RV wall was measured at 8.7 mm, a noted improvement over the pre-surgical value of 10.1 mm. With Doppler measurements, turbulence through the pulmonic valve was still apparent, but the clinician was again unable to obtain an accurate angle to calculate a gradient value.

On July 5, 1994 the animal was found to have a RV wall measurement of 4.7 mm to 6.0 mm. During this follow-up, the correct Doppler angle was obtained allowing for the calculation of a pressure gradient value of 13.2 mmHg. On December 20, 1994, continued improvement in the condition was noted as the RV wall measurement has decreased to 4.1 mm to 5.0 mm. On his last re-check on September 5, 1996, his pressure gradient was 25 mmHg, and it was noted that there was little change in the cardiac condition from previous visits.

Discussion

Pulmonic stenosis is a malformation of the pulmonary artery which may be apparent in dogs, cats, and human beings. Within the canine community, the Beagle, Bulldog, Samoyed, White Fox Terrier, Chihuahua, Miniature Schnauzer, and Keeshond breeds have been observed to have a higher occurrence of this abnormality (Fingland, 1986).

A pulmonic stenosis may occur at three possible locations in relation to the pulmonic valve. The stenosis is termed subvalvular, valvular, or supravavular, depending on the orientation of the stenosis, with the valvular pulmonic stenosis being the most common type of obstruction.

As in this case, pulmonic stenosis is most often detected in normal puppies by the occurrence of a systolic ejection murmur. Other typical characteristics associated with pulmonic stenosis including right ventricular hypertrophy, poststenotic dilatation of the main pulmonary artery, and a main pulmonary artery bulge or cap, were also evident in this particular animal (Fingland, 1986).

M-mode, B-mode, and Doppler ultrasound played integral roles in the determination of the post-operative condition of the animal. Motion, or M-mode was used to compute the Fractional Shortening Value, which is an indication of the contractile function of the left heart. Brightness, or B-mode was utilized to provide a real-time image of the heart for anatomical evaluation, especially the thickness of the outflow tract muscle. Finally, Doppler techniques were

necessary to determine the blood velocities in the region of the stenosis and thus compute pressure gradients. The non-invasive nature of the Doppler evaluation allows a convenient way to monitor the pressure gradient status. Otherwise, a more invasive catheterization technique would have to have been performed.

Although, Doppler is non-invasive, it does have a limitation in that the Doppler angle must be correct in order to obtain an accurate value for velocity to be inserted into the Bernoulli equation. The compromised pressure gradient reading on May 8, 1992 of 20.4 mmHg exemplified the necessity of obtaining an accurate angle. As I reviewed the case notes this sharp reduction in the pressure gradient was quite surprising, especially since the RV wall hypertrophy had worsened since the previous visit. Upon discussion with the evaluating clinician, I learned that obtaining an appropriate Doppler angle was difficult with this particular animal, and this was indeed the cause of the inaccurate pressure gradient value.

Future Trends

Technical advances, widespread education and recognition of its diagnostic capabilities have led to the dramatic increase in ultrasound usage over the past decade. As we approach the turn of the century, new trends and applications in ultrasound are being uncovered. Many of these new techniques are still in the experimental stage, but as their ability to aid the physician in the diagnostic

process are quantified, the procedures will become an important tool in the quest for early disease detection.

One such technique, Power Doppler, is rapidly gaining acceptance among the medical community. "Power Doppler displays the amplitude of the Doppler signal in color, rather than the speed and direction information" (Babcock et al., 1996, p. 109) This new form of Doppler ultrasound has three times the sensitivity of conventional color Doppler for detection of flow. For this reason it is particularly useful for small vessels and those with low velocity flow. In experimental testing, Power Doppler has show potential for being a useful tool in the detection of ischemia in the kidney, brain, and prepubertal testis, hyperemia in areas of inflammation, (Babcock et al., 1996) vascularization of breast lesions and liver tumors, (Choi, 1996) and stenosis of the carotid artery (Griewing et al., 1996).

Another new development know as two-dimensional transesophageal echocardiography involves the endoscopic placement of an ultrasound transducer within the esophagus subjacent to the heart. The close proximity allows for better quality images and thus improved diagnostic information. Through studies conducted at the University of Louisville Department of Medicine it has been show to be an "accurate method of measuring aortic valve area in patients with aortic stenosis" (Stoddard et al., 1996, p. 337). An offshoot of this method incorporates Doppler. Doppler transesophageal echocardiography has also been shown to

produce accurate measurements. Consequently, it is used to complement the two-dimensional transesophageal echocardiography.

The American Heart Journal recently cited intravascular ultrasound as a "reliable technique for accurate assessment of vascular anatomic structure and disease conditions before and after intervention" (Gussenhoven et al., 1996, p. 702). This advancement enhances diagnostic differentiation of plaque morphologies, as well as providing a quantitative assessment of vessel structure (Gussenhoven et al., 1996).

Additional techniques on the medical forefront include endobronchial ultrasound, acoustic quantification, ultrasound contrast agents, and Doppler myocardial imaging. Endobronchial ultrasound is being utilized in the diagnosis of mediastinal disease (Becker, 1996). Through software enhancement, acoustic quantification provides a more direct assessment of the health of the myocardium (Goens & Martin, 1996). New ultrasound contrast agents such as Levovist, have led to the detection of tumor vessels not previously detectable by traditional color flow imaging (Ernst, 1996). Finally, Doppler myocardial imaging is a new technique which illustrates color Doppler imaging of the cardiac structures themselves. This advancement has been heralded as providing new information on myocardial contractile function, diastolic function, myocardial perfusion, and myocardial structure (Sutherland, 1996).

Conclusion

Heart disease and cancer claim hundreds of thousands of victims worldwide every year. The medical community continually strives to develop new techniques to aid in the early detection and diagnosis of such diseases. Doppler ultrasound is one such development which the medical field has widely embraced. With its new technological implements, increasing scope of application, and its broad acceptance and usage throughout the medical arena, Doppler ultrasound is a powerful tool with increasing diagnostic capabilities.

Although currently being utilized for many types of cardiovascular disease, such as the pulmonic stenosis case illustrated in this paper, experimental testing foreshadows the wider reach of ultrasound in years to come. As today's experimental practices become commonplace medical procedures of the future, the physician's diagnostic ability will continue to be enhanced. Doctors are looking to that next "new advancement" in the hopes that the course of a disease might be circumvented and the patient will be spared from an early demise.

Acknowledgments:

I would like to thank Dr. Robert Toal, for all the time, information, and guidance he provided as my faculty mentor over the past year. I would also like to thank Dr. Larry E. Davis, and Dr. John Kennedy, for all their help and support as members of my project committee.

Finally, I would like to thank Dr. Thomas Broadhead, Director of the University Honors Department, Mr. J.J. Brown, Associate Director of the University Honors Department, Mrs. Mary Ann Bright, Secretary of the University Honors Department, and Dr. Jack Reese, Chancellor Emeritus and Director of the College Scholars Program. It has been an honor and privilege to be a member of both the University Honors and College Scholars Program at the University of Tennessee, Knoxville.

References:

- Babcock, D.S., et al. "Power Doppler sonography: basic principles and clinical applications in children." Pediatric Radiology. 26 (1996): 109-15.
- Becker, H. "Endobronchial Ultrasound-a new perspective in bronchology." Ultrasound Medicine. 17 (1996): 106-12.
- Burns, Peter N., Ph.D.. "The Physical Principles of Doppler and Spectral Analysis." Journal of Clinical Ultrasound. 15 (1987): 567-590.
- Bushong, Stewart C. Radiologic Science for Technologists. St. Louis: Mosby, 1993.
- Chio, B. et al. "Power versus conventional color Doppler sonography: comparison in the depiction of vasculature in liver tumors." Radiology. 200 (1996): 55-8.
- Christensen, Edward, Thomas S. Curry, III, and James E. Dowdey. An Introduction to the Physics of Diagnostic Radiology, 4th Ed. Philadelphia: Lea & Febiger, 1994.
- Ernst, H., et al. "Color Doppler Ultrasound of liver lesions: signal enhancement after intravenous injection of the ultrasound contrast agent Levovist." Journal of Clinical Ultrasound. 24 (1996): 31-5.
- Evans, D.H., W.N. McDiken, R. Skidmore, et al. Doppler Ultrasound Physics, Instrumentation and Physical Principles. New York: Churchill Livingstone, 1989.
- Fingland, Roger B., DVM, M.S., et al. "Pulmonic stenosis in the dog: 29 cases (1975-1984)." JAVMA 189 (1986): 218-226.
- Goens, M. and G. Martin. "Acoustic quantification: a new tool for diagnostic echocardiography." Current Opinions-Cardiology. 11 (1996): 52-60.
- Goldberg, Stanley J., et al. Doppler Echocardiography. Philadelphia: Lea & Febiger, 1985.
- Griewing, B., et al. "Cerebrovascular disease assessed by color-flow and Power Doppler ultrasonography." Stroke. 27 (1996); 95-100.

- Gussenhoven, E., et al. "What have we learned from in vitro intravascular ultrasound?" American Heart Journal. 132 (1996): 702-10.
- Jawad, Ibrahim A., M.D. A Practical Guide to Echocardiography and Cardiac Doppler Ultrasound. Boston: Little, Brown and Company, 1990.
- Kremkau, Fredrick W., Ph.D.. Doppler Ultrasound- Principles and Instruments. Philadelphia: W.B. Saunders Company, 1990.
- Kremkau, Fredrick W., Ph.D.. "Doppler Principles." Seminars in Roentgenology. 27 (1992): 6-16.
- McGahan, John P., ed. Interventional Ultrasound. Baltimore: Williams & Wilkins, 1990.
- Miskovits, Christine. Echocardiography. New York: Medical Examination Publishing Company, Inc., 1977.
- Missri, Jose, M.D. Clinical Doppler Echocardiography. New York: McGraw-Hill Information Services Company, 1990.
- Sochurek, Howard. Medicine's New Vision. Easton: Mack Publishing Company, 1988.
- Stoddard, M., et al. "Doppler transesophageal echocardiographic determination of aortic valve area in adults with aortic stenosis." American Heart Journal. 132 (1996): 337-42.
- Sutherland, G. "Color Doppler myocardial imaging: potential applications in acquired and congenital heart disease." Acta Pediatric Supplement. 410 (1995): 40-8.
- Taylor, Kenneth J.W., M.D., Ph.D., and Scott Holland, Ph.D.. "Doppler US." Radiology 174 (1990): 297- 307.
- Toal, Robert, DVM. Ultrasound for the Practitioner. Wallingford: Corometrics Medical Systems, Inc., 1994.
- Webb, Shelly Dee. "Theory and Applications of the Doppler Effect." Diss. The University of Tennessee, Knoxville, 1993.
- Wicks, Jeffery D., M.D. Fundamentals of Ultrasonographic Technique. Chicago: Year Book Medical Publishers, Inc., 1983.